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UCRL-CONF-203798

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April 27, 2004

15th Topical Conference on High-Temperature Diagnostics
San Diego, CA, United States
April 19, 2004 through April 22, 2004

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Calibration of Initial Measurements from the Full Aperture Backscatter System on NIF

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Abstract

The Full Aperture Backscatter System (FABS) provides a measure of the spectral power, and integrated energy scattered by stimulated Brillouin (348-354 nm) and Raman (400 – 700 nm) scattering into the final focusing lens of the first four beams of the NIF laser. The system was designed to provide measurements at the highest expected fluences with: 1) spectral and temporal resolution, 2) beam aperture averaging, and 3) near-field imaging. This is accomplished with a strongly attenuating diffusive fiber coupler and streaked spectrometer and separate calibrated time integrated spectrometers, and imaging cameras. Measurement of the wavelength dependent sensitivity of the complete system is accomplished with a calibrated Xe lamp. Data from the calibration system is combined with experimental data to produce the power and energy measurements. Examples of measurements will be discussed.

Ignition experiments and high energy density science experiments at the National Ignition Facility rely on efficient coupling of the laser energy to the target. One important energy loss mechanism is scattering of the incident beam by the plasma surrounding (or making up) the target. Both ion and electron waves are driven to large amplitude in the plasma by the processes of stimulated Brillouin and Raman scattering (SBS and SRS respectively). When the beam intensity is high, these waves can produce scattering well above the thermal scattering level. The NIF facility will operate a suite of diagnostics to measure scattered energy and power. The first of these systems to operate is the Full Aperature Backscatter System (FABS) which collects light scattered back into the final focus lens of the beams. FABS measurements are presently operational on four beams and are planned for as many as 20 of the 192 NIF beams. The FABS can produce a calibrated measurement of the power spectral density in the ranges of SBS (348 nm -354 nm) and SRS scattering (400 – 700 nm with extensions to 800 nm). The FABS was designed to collect the backscattered light over the full beam aperture by viewing through a turning mirror for the incident beam which has significant transmission of these spectral components. The signal in each of four beams is collected by a single surface pickoff, and a focusing mirror before being directed to an optical table for coupling to the time streaked and time integrated spectrometers and near field imaging cameras as shown in figure 1 and described in more detail in Refs. [2,3]. The signal to the spectrometers is accurately (+-10%) averaged over the beam aperture with a diffuser plate coupler as shown in figure 2, while the near field cameras view an image take from a second splitter and passed through band pass filters. A spot containing all light coupled from a +- 5 cm region around the target is produced on the

diffuser which for SRS and time integrated SBS measurements is viewed by a 100 micron diameter fiber that is placed far enough from the diffuser that it included the entire spot within its region of sensitivity. For the SBS time resolved measurements a 10x magnification is used to relay the far field of the diffuser plate to the fiber so that the entire diffuser spot is included in an f/50 cone which can then be propagated through the spectrometer using a small enough diffraction grating that the time smearing is less than 50 ps. The coupler provides the needed signal averaging for all wavelengths studied, and also attenuates the signal by ~ 1 x 10^8 bringing the signals down close to the levels required by the detectors. The final adjustment of the detector signal level is made by a single small broad band filter in each detector, and a series of large area, colored glass filters (NG11 for SRS, UG1, and UG11 for SBS) that are placed up stream of all detector pickoffs. This arrangement allows for balance between the detectors to be set by the small filters and to be adjusted infrequently, while the variations in the incident signal can be accommodated by a single adjustment of the large filters before each experiment. The large attenuation that must be introduced in the scattered light to bring its level down to that needed for the detectors must be accurately known to allow for precise measurements of the scattered light and is calibrated separately. Because the attenuation depends on wavelength over both bands, and is due to the product of the transmission of a large number of components, the total system sensitivity (in the absence of filters) is measured using a calibrated source at the chamber center and the signal it produces on the time integrated spectrometer. The time integrated spectrometer used for the system calibration both because it has a higher SBS sensitivity than the streak cameras (due largely to its lower collection f/number), and because the sensitivity of the CCD in this

instrument is believed to be more stable than that of the image intensified streak camera. Once the time integrated spectrometer is calibrated it is used to measure the J/nm scattered in each band during a target shot. The streak camera simultaneously obtains spectral power density data that is absolutely calibrated at each value of wavelength using the data from the calibrated measurement from time integrated spectrometer to produce a measure of W/nm over both wavelength ranges that is absolutely calibrated at each wavelength. The NIF FABS is the first backscatter measurement to be calibrated both through the complete system and over the entire spectrum and as a result has significantly improved accuracy over previous systems on the Nova [4] and Omega [5] lasers.

The light source used to give the needed brightness, broad spectral range, and high reproducibility, is a Xe lamp that is operated for up to 1 hr exposures (mfg. By Oriel) and produces the output spectrum shown in figure 3. A calibration lamp 30 min. exposure is taken with all neutral density and colored glass filters removed, and calibration data is collected the time integrated spectrometer. The calibration spectrometer detector is a CCD camera that collects four signals from four fibers (one from each of four beams) that are multiplexed in the input slit of the spectrometer by displacement in the direction transverse to the direction of spectral dispersion. The signal from each fiber appears on a different region of the CCD and is averaged over the transverse direction to maximize signal to noise. The resulting spectrum is further averaged over five pixels in the spectral direction which corresponds to the minimum spot size that the optical system can resolve. The spectral resolution is therefore determined by the optical system and can be as high as 2.5 nm for SRS and 0.6 nm for SBS. The resolution both of these spectrums is what is necessary to resolve variations in

instrument sensitivity with wavelength, but in the case of SBS is not as high as the resolution that will be achieved in measuring the target scattering spectrum (as discussed below).

For target experiments, the small area neutral density filter is replaced in the integrated spectrometer, the colored glass filters are added as appropriate to the expected signal, and data is collected in all FABS instruments. The calibration camera data can then be multiplied by the measure calibration lamp power spectrum spectrum and exposure time and divided by the calibration data to produce a measure of the scattered J/nm in both SBS and SRS bands. An example of the raw and calibrated target scattering spectrum from a 7mm long, CO2 filled target illuminated with 16kJ in a 2 ns pulse to produce 2 x 10^{15} W/cm^2 peak at the target [1] is shown in figure 4.

The total scattered energy can be most accurately determined from the FABS data by integrating the time integrated spectrometer data, as shown in figure 4, over wavelength, to provide a measure of Joules scattered in each of the SBS and SRS channels. This process shows the total energy scattered in the wavelength range, which on this shot was 4.52 J of SRS. Similar measurements were made of the SBS scattered energy spectrum which was sufficiently narrow that the wavelength dependence of the detectors does not make a significant correction to the integrated energy, and the total scattered energy in the SBS channel was 156 J on this shot. A separate system for measuring total energy, the FABS also has a pickoff in each of the SRS and SBS legs to direct the signal to a calorimeter, which during initial experiments gave values within 25% of the calibrated spectrometer data which is consistent with the limited accuracy of the transmission

models used to interpret calorimetry data. Nonetheless, this close an agreement with the calorimeter data increases our confidence in the system calibration procedure.

The calibrated time integrated spectrum is then used to correct the spectral sensitivity of the streaked spectrum. For the SRS spectrum this is done simply by multiplying the streak image at each wavelength by a calibration constant equal to the energy spectral density measured by the calibration camera divided by the integral of the streak signal at that wavelength over the time window. For the SBS spectrum the spectral resolution of the streaked spectrum is reduced to match the resolution of the time integrated spectrum when it is time integrated to evaluate the calibration constant. The streak data that is multiplied by the calibration constant retains its high resolution, so that only the spectral correction to the system sensitivity has the reduced resolution. The results is a calibrated measure of power spectral density vs. time and wavelength, that has all the measured wave length dependence of the sensitivity accounted for, and example of a calibrated SRS streaked spectrum is shown in figure 5 for the experiment shown in figure 4. Although the full system calibration is incorporated in the figure 5 data the complete characterization of the streak camera linearity is still in process and has not been included. For the streaked SBS spectrum from this shot, the spectral width was sufficiently small that there was no significant correction to the raw streaked spectrum shown in Ref. [2] and the calibrated spectral measurements were only used to determine the total scattered energy.

In conclusion, a new technique has been developed to calibrate backscatter measurements on NIF that properly measures and accounts for the wavelength dependence of all components in the optical path, and provides an empirical calibration

constant for the entire system at each wavelength. This system has been fielded in the initial operation of FABS on NIF and provides calibrated total scattered energy, energy spectral density, and power spectral density measurements in both the SRS and SBS wavelength ranges. The data shows that particularly for the broad band SRS spectrum the accumulated spectral properties of the optics and detectors in the path make a significant correction the the measures spectrum and energy.

Figure 1a Physical layout of the FABS diagnostic on the NIF Q31B beam showing position of turning mirror for the incident beam as well as the signal collection optics

Figure 1b Optical layout of the FABS diagnostic showing large opics, optical table with small optics and detectors

Figure 2 Diffusive coupler for SBS leg shows holographic diffuser, fiber and coupling lens. The coupler for SRS is the same but without the coupling lens.

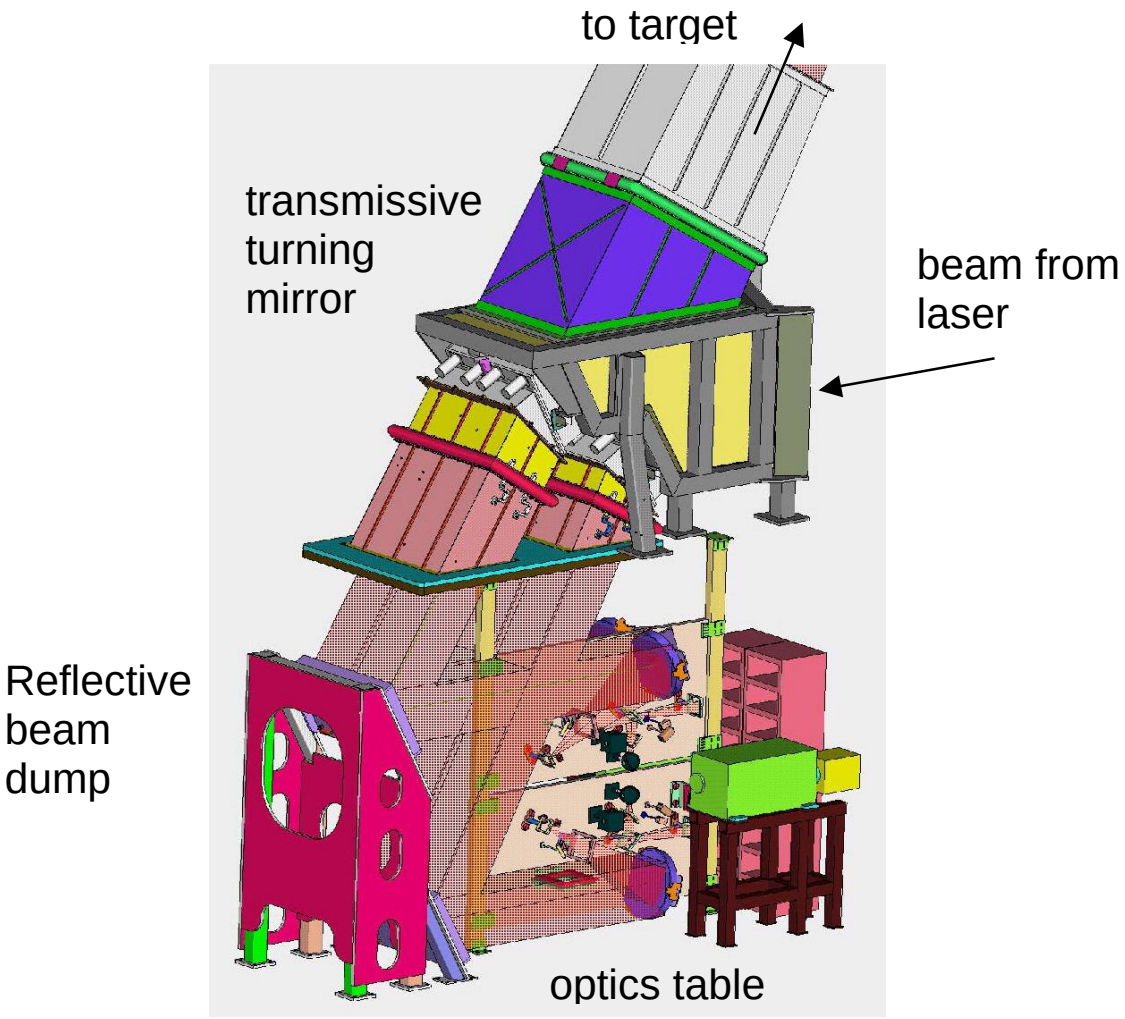
Figure 3 Measured output spectrum of Xe calibration lamp used to calibrate FABS from chamber center to the detector output.

Figure 4 Time integrated SRS spectrum, including 'ghost' feature at 527 nm, both before lamp calibration data is applied (a) and after (b). Note calibration with the lamp provides both the absolute measure of the spectral energy density that is integrated to get total scattered energy and a correction to the shape of the spectrum. Similar data is taken for SBS where there is no significant correction to the spectral shape.

Figure 5 The calibrated time integrated spectrum is also used to correct the spectral shape of the streaked spectrum of scattered light. The SRS spectrum shown is significantly broader when correctly calibrated (a) than before correction (b).

[1] S. H. Glenzer paper on target expts. (IFSA?)
[2] D. H. Froula et. al. these proceedings.
[3] D. Bower et al., these proceedings.
[4] R. Kirkwood et al., Rev. Sci. Inst. 68, 636 (1997)
[5] C. G. R. Geddes, et al., 29th Conference on Anomalous Absorption, Pacific Grove, Ca. June13-18, 1999

This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.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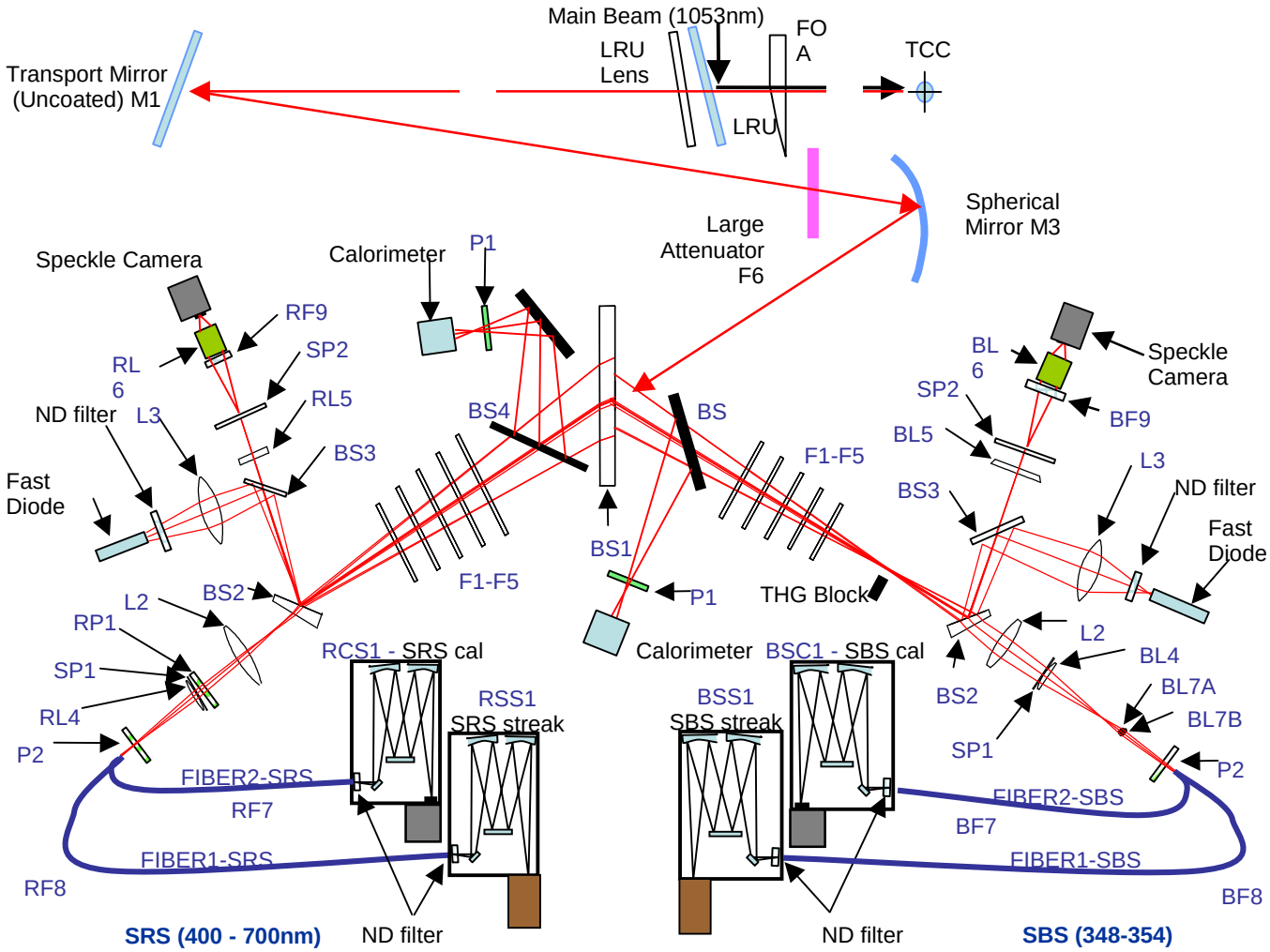
mirror
beam from
laser
Reflective
beam
dump
optics table

Figure 1a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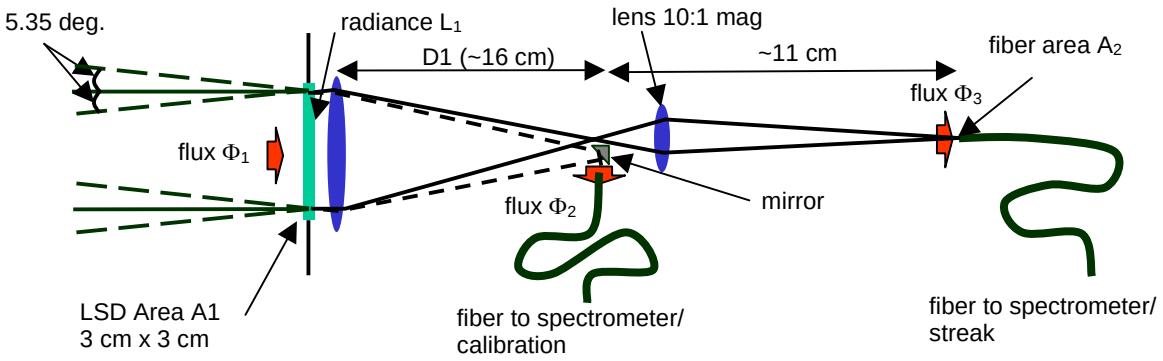
Speckle Camera
Calorimeter
P1
RF9
SP2
RL
6
RL5
ND filter
L3
BS3
Fast
Diode
BS4
BS
F1-F5
BS1
P1
THG Block
F1-F5
BL
6
Speckle
Camera
SP2
BF9
BL5
L3
BS3
ND filter
Fast
Diode
L2
BS2
RP1
SP1
RL4
P2
RCS1 - SRS cal
RSS1
SRS streak
Calorimeter
BSC1 - SBS cal
BSS1
SBS streak
L2
BL4
BS2
BL7A
BL7B
SP1
P2
FIBER2-SRS
RF7
FIBER1-SRS
RF8
FIBER2-SBS
BF7
FIBER1-SBS
BF8
SRS (400 - 700nm)
ND filter
ND filter
SBS (348-354)

Figure 1b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3 cm x 3 cm
fiber to spectrometer/
calibration
fiber to spectrometer/
streak

Figure 2

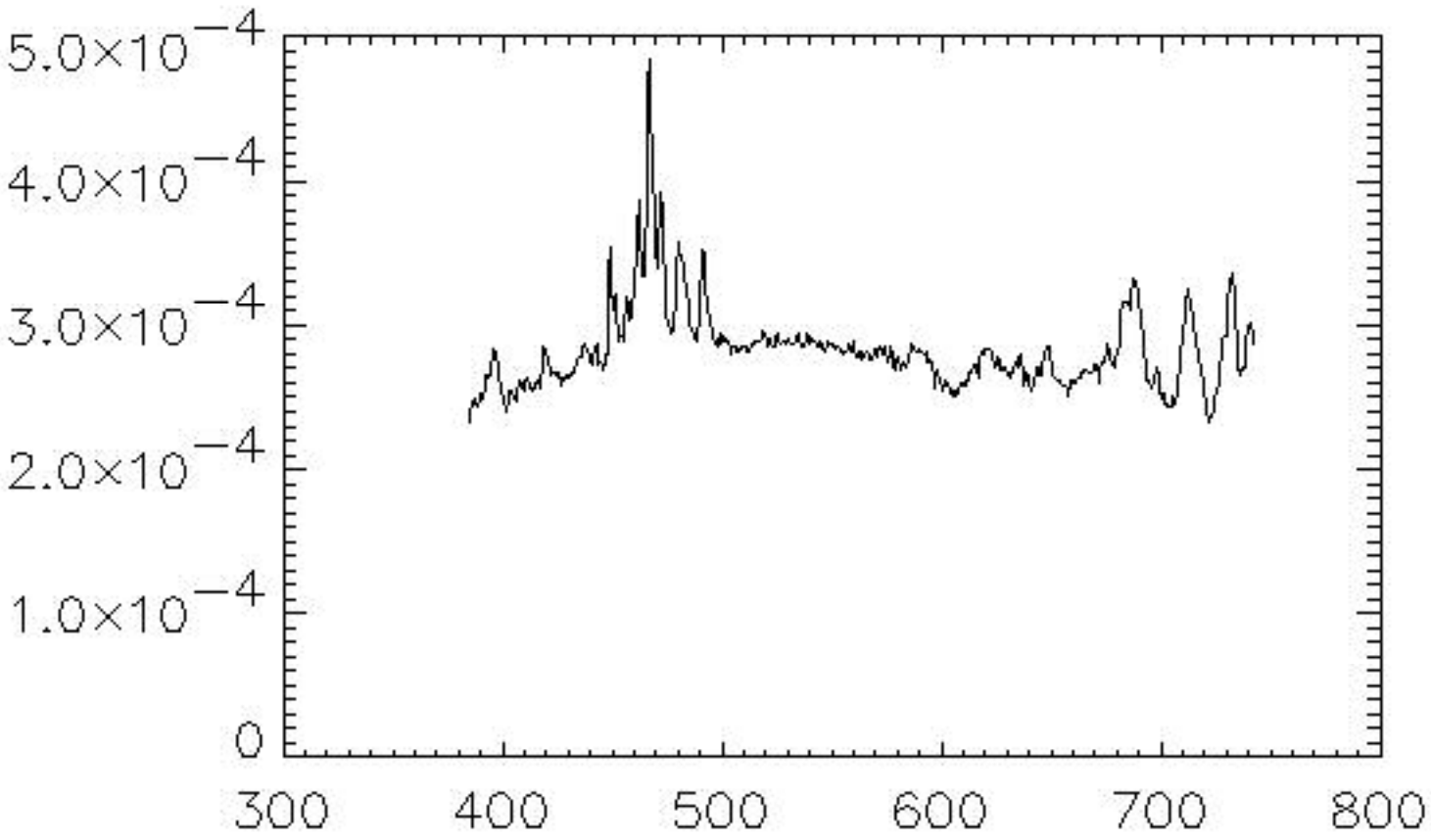

Figure 3

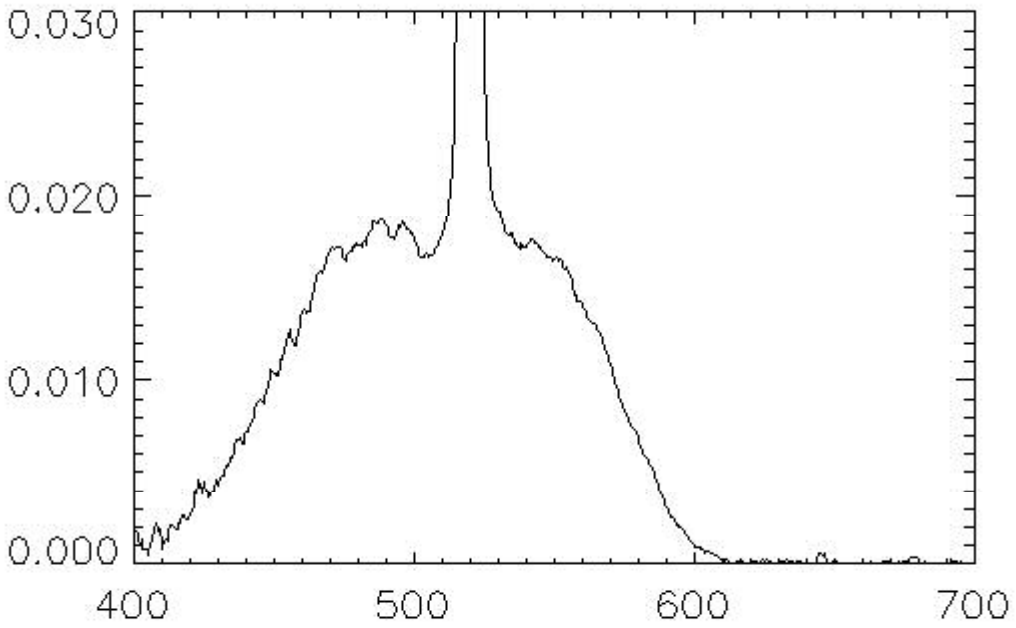

Figure 4a

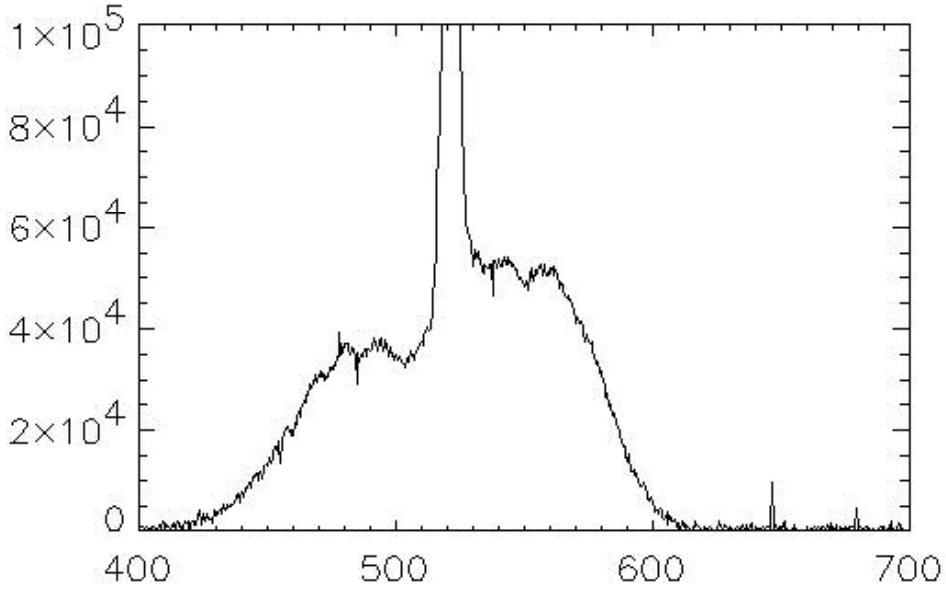

Figure 4b

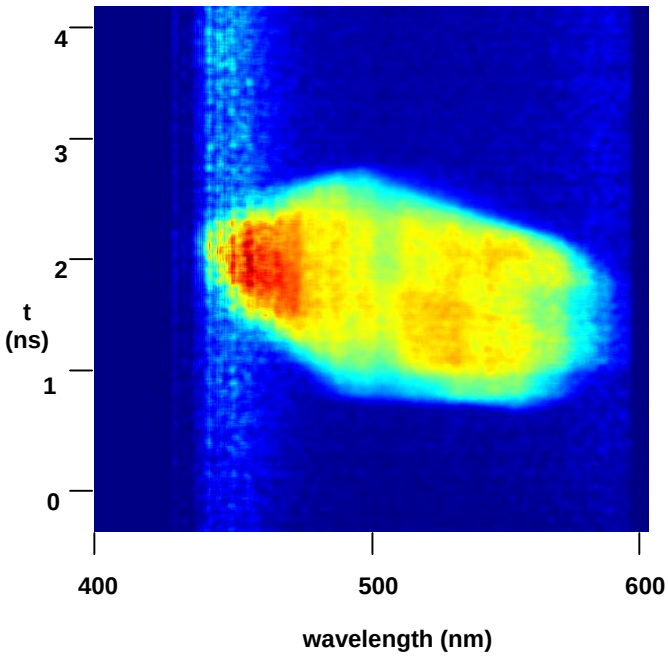

Figure 5a

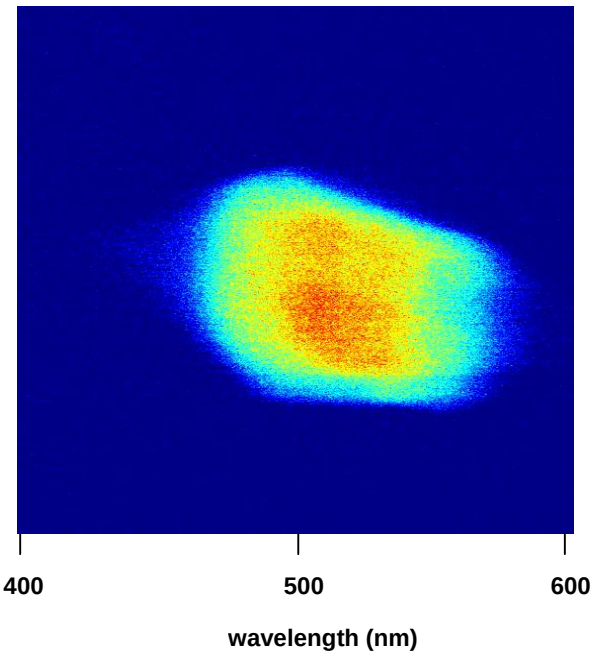

Figure 5b